Photovoltaic Systems

2.1 Introduction

Photovoltaic (or PV) **systems** convert light directly into electricity. The term photo comes from the Greek phos, which means "light." The term volt is a measure of electricity named for Alessandro Volta (1745- 1827), a pioneer in the development of electricity. Photovoltaics literally mean light–electricity.

Commonly known as solar cells, PV cells are already an important part of our lives. The simplest PV systems power many of the small calculators and wrist watches we use every day. Larger PV systems provide electricity for pumping water, powering communications equipment, and even lighting homes and running appliances.

In certain applications, such as motorist aid call boxes on highways and pumping water for livestock, PV power is the cheapest form of electricity. Some electric utility companies are building PV systems into their power supply networks.

Figure 2.1 a solar cell provides power to this traffic signal. Attached to the support pole are two boxes: one that stores batteries for operation while it's dark, and one that houses a control panel.

2.1.1 History of Photovoltaic

French physicist Edmond Becquerel first described the photovoltaic effect in 1839, but it remained a curiosity of science for the next half century. At the age of 19, Becquerel found that certain materials would produce small amounts of electric current when exposed to light. The effect was first studied in solids, such as selenium, by Heinrich Hertz in the 1870s. Soon selenium PV cells were converting light to electricity at one to two percent efficiency.

The conversion efficiency of a PV cell is the proportion of radiant energy the cell converts into electrical energy relative to the amount of radiant energy that is available and striking the PV cell. This is very important when discussing PV devices, because improving this efficiency is vital to making PV energy competitive with more traditional sources of energy, such as fossil fuels.

During the second half of the 20th century, PV science was refined and the process more fully developed. Major steps toward commercializing photovoltaic were taken in the 1940s and 1950s, when the Czochralski process was developed for producing highly pure crystalline silicon.

In 1954, scientists at Bell Laboratories depended on the Czochralski process to develop the first crystalline silicon photovoltaic cell, which had a conversion efficiency of four percent.

As a result of technological advances, the cost of PV cells has decreased significantly over the past 25 years, as the efficiency has increased. Today's commercially available PV devices convert 7 to 17 percent of the radiant energy that strikes them into electricity.

In the laboratory, combining exotic materials with specialized cell designs has produced PV cells with conversion efficiencies as high as 43 percent The current expense of these technologies typically restricts their use to aerospace and industrial applications, where the unit cost of a solar array that powers, for example, a satellite is a minor concern.

2.1.2 Photovoltaic Effect

The photovoltaic effect is the basic physical process through which a PV cell converts sunlight directly into electricity. PV technology works any time the sun is shining, but more electricity is produced when the light is more intense and when it is striking the PV modules directly—when the rays of sunlight are perpendicular to the PV modules.

Unlike solar systems for heating water, PV technology does not produce heat to make electricity. Instead, PV cells generate electricity directly from the electrons freed by the interaction of radiant energy with the semiconductor materials in the PV cells.

Sunlight is composed of photons, or bundles of radiant energy. When photons strike a PV cell, they may be reflected, absorbed, or transmitted through the cell.

Only the absorbed photons generate electricity. When the photons are absorbed, the energy of the photons is transferred to electrons in the atoms of the solar cell, which is actually a semiconductor.

With their new-found energy, the electrons are able to escape from their normal positions associated with their atoms to become part of the current in an electrical circuit. By leaving their positions, the electrons cause holes to form in the atomic structure of the cell into which other electrons can move. Special electrical properties of the PV cell—a built-in electric field— provide the voltage needed to drive the current through a circuit and power an external load, such as a light bulb.

Figure 2.2 Image courtesy of NASA

2.1.3 Photovoltaic Cells

The basic building block of PV technology is the **photovoltaic cell**, Different materials are used to produce PV cells, but silicon—the main ingredient in sand—is the most common basic material. Silicon, a common semiconductor material, is relatively cheap because it is widely available and used in other things, such as televisions, radios, and computers. PV cells, however, require very pure silicon, which can be expensive to produce.

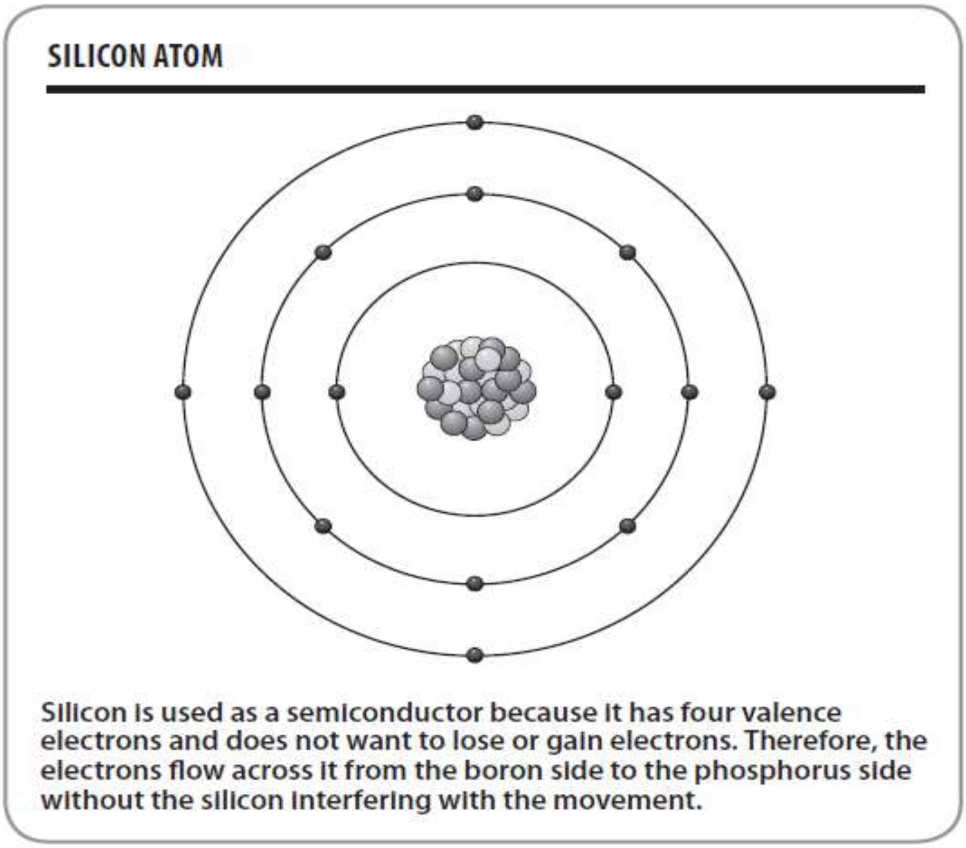

Figure 2.3 The silicon Atom

The amount of electricity a PV cell produces depends on its size, its conversion efficiency, and the intensity of the light source. Efficiency is a measure of the amount of electricity produced from the sunlight a cell receives.

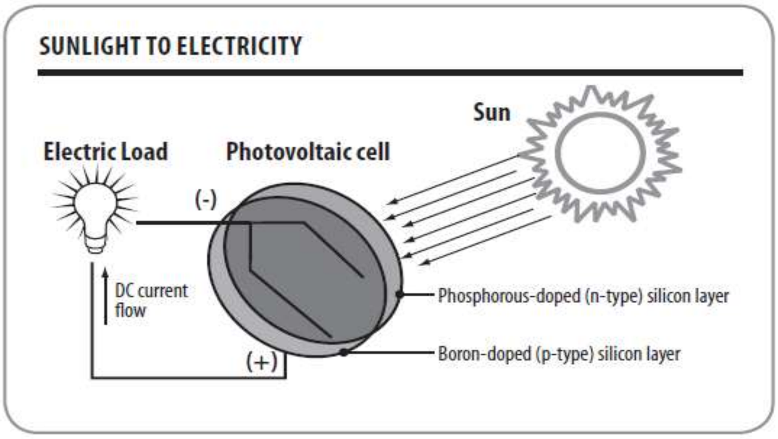

Figure 2.4 Sunlight To Electricity

A typical PV cell produces 0.5 volts of electricity. It takes just a few PV cells to produce enough electricity to power a small watch or solar calculator.

The most important parts of a PV cell are the **semi-conductor** layers, where the electric current is created. There are a number of different materials suitable for making these semi-conducting layers, and each has benefits and drawbacks. Unfortunately, there is no one ideal material for all types of cells and applications.

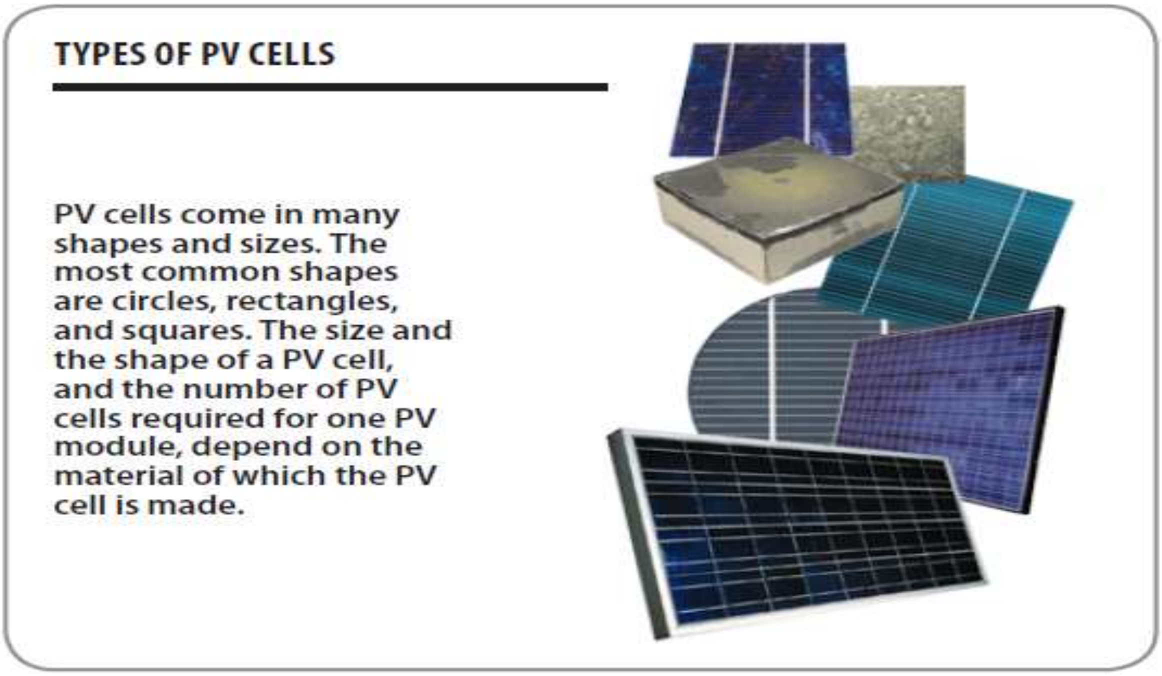

Figure 2.5 Types of PV cells

2.1.4 Traditional Made of PV Cell

Steps of fabricating PV cell shown in figure 2.6

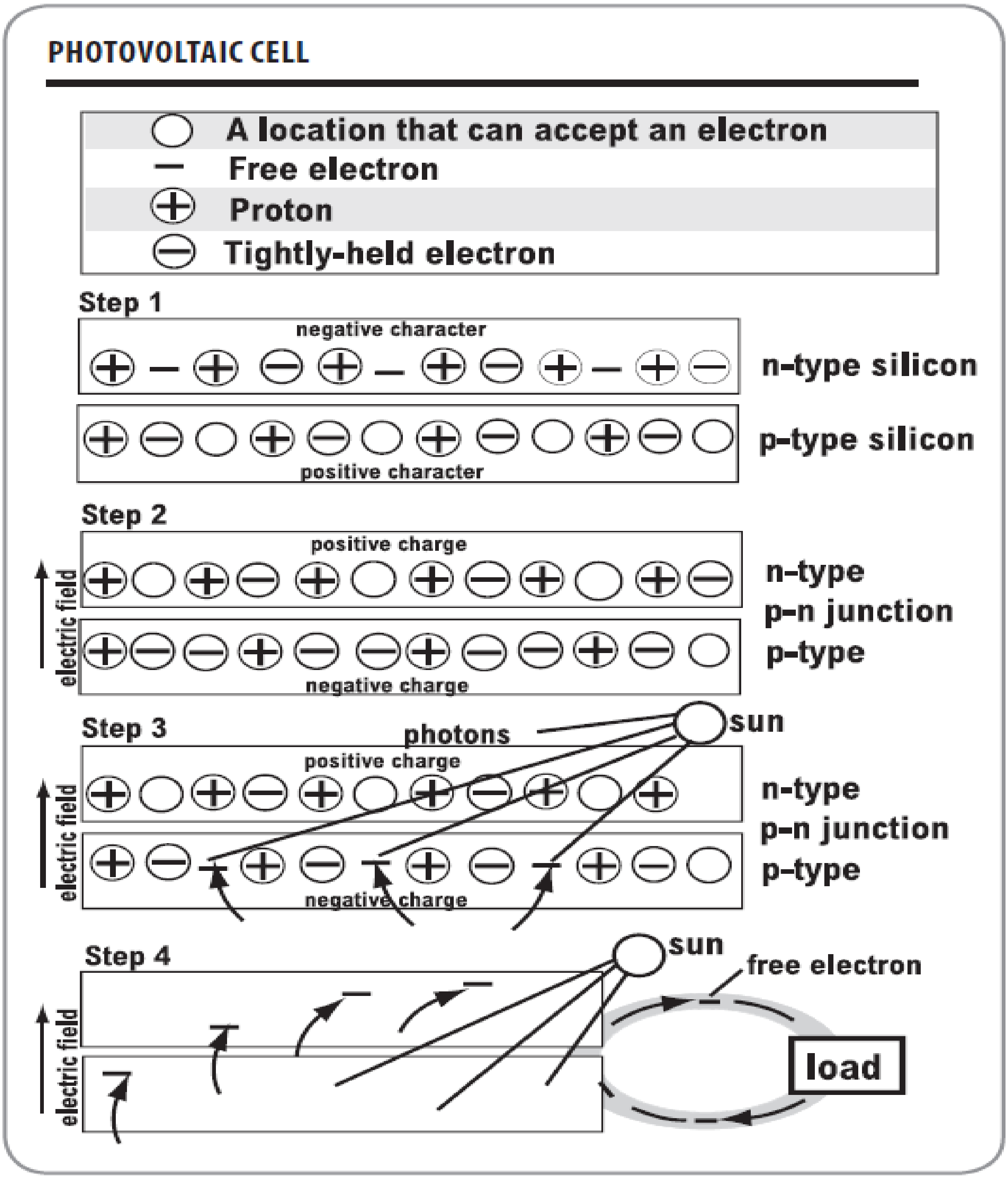

Figure 2.6 How PV cell produces electricity

Steps of fabricating PV cell and how it produces electricity:

Step 1

A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with an "n" dopant, such as phosphorous. On the base of the slab, a small amount of a "p" dopant, typically boron is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side. Dopants are similar in atomic structure to the primary material. The phosphorous has one more electron in its outer shell than silicon, and the boron has one less.

These dopants help create the electric field that motivates the energetic electrons out of the cell created when light strikes the PV cell.

The phosphorous gives the wafer of silicon an excess of free electrons; it has a negative character. This is called the **n-type silicon**. The n-type silicon is not charged—it has an equal number of protons and electrons but some of the electrons are not held tightly to the atoms. They are free to move to different locations within the layer.

The boron gives the base of the silicon wafer a positive character, which will cause electrons to flow toward it. The base of the silicon is called **p-type silicon** (p = positive). The p-type silicon has an equal number of protons and electrons; it has a positive character, but not a positive charge.

Step 2

Where the n-type silicon and p-type silicon meet, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the **p-n junction**.When both sides of the silicon slab are doped, there is a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction due to movement of the electrons and "holes" at the junction of the two types of materials. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type.

Step 3

If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-type silicon and repelled by the negative charge in the p-type silicon. Most photon-electron collisions actually occur in the silicon base.

Step 4

A conducting wire connects the p-type silicon to an external load such as a light or battery, and then back to the n-type silicon, forming a complete circuit. As the free electrons are pushed into the n-type silicon, they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that can power a load, such as a calculator or other device, as it travels through the circuit from the n-type to the p-type.

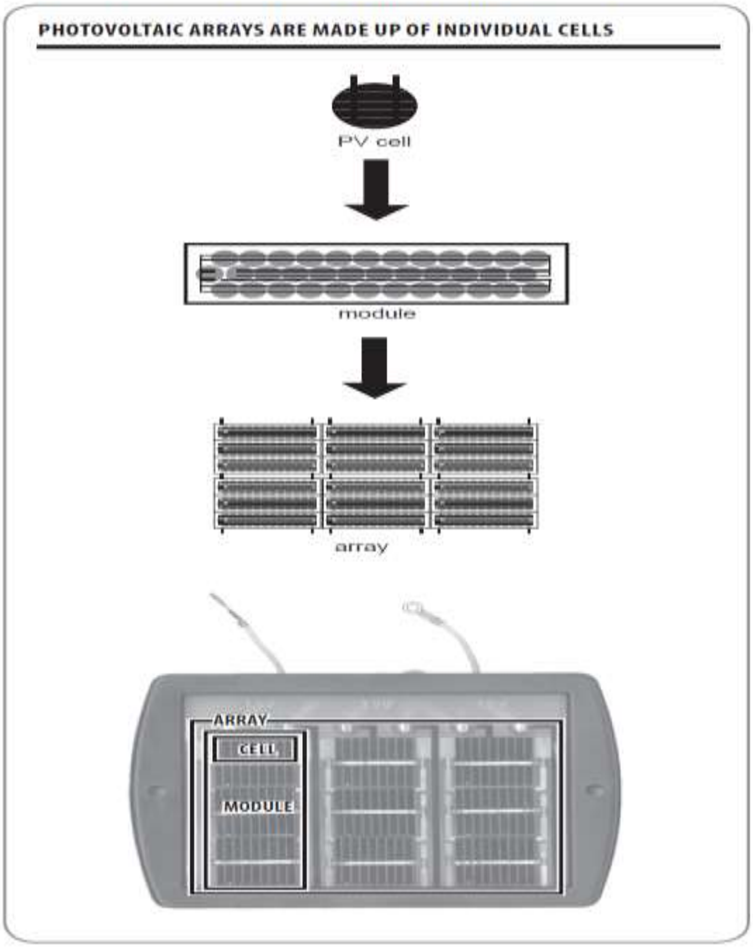

Figure 2.7 Made of photovoltaic arrays

In addition to the semi-conducting materials, solar cells consist of a top metallic grid or other electrical contact to collect electrons from the semi-conductor and transfer them to the external load, and a back contact layer to complete the electrical circuit.

2.1.5 PV Modules and Arrays

For more power, PV cells are connected together to form larger units called **modules**. Photovoltaic cells are connected in series and/ or parallel circuits to produce higher voltages, currents, and power levels. A PV module is the smallest PV component sold commercially, and can range in power output from about 10 watts to 300 watts.

A typical PV module consists of PV cells sandwiched between a clear front sheet, usually glass, and a backing sheet, usually glass or a type of tough plastic. This protects them from breakage and from the weather. An aluminum frame can be fitted around the PV module to enable easy affixing to a support **arrays** include one or more PV modules assembled as a pre-wired, field- installable unit. A PV array is the complete power-generating unit, consisting of any number of modules and panels.

2.1.6 PV System Components

Although a PV module produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array. Depending on the type of system, these components may include:

2.1.6.1 Power Inverter

PV modules, because of their electrical properties, produce direct current rather than alternating current. **Direct current (DC)** is electric current that flows in a single direction. Many simple devices, such as those that run on batteries, use direct current. **Alternating current (AC)**, in contrast, is electric current that reverses its direction of flow at regular intervals (120 times per second).

This is the type of electricity provided by utilities, and the type required to run most modern appliances and electronic devices.

In the simplest systems, DC current produced by PV modules is used directly. In applications where AC current is necessary, an **inverter** can be added to the system to convert DC to AC current.

2.1.6.2 Battery System

PV systems cannot store electricity, so batteries are often added. A PV system with a battery is configured by connecting the PV array to an inverter. The inverter is connected to a battery bank and to any load. During daylight hours, the PV array charges the battery bank. The battery bank supplies power to the load whenever it is needed. A device called a **charge controller** keeps the battery properly charged and prolongs its life by protecting it from being overcharged or completely discharged.

PV systems with batteries can be designed to power DC or AC equipment. Systems operating only DC equipment do not need an inverter, only a charge controller.

It is useful to remember that any time conversions are made in a system, there are associated losses. For example, when an inverter is used there is a small loss of power that can be described by the inverter's conversion efficiency. Likewise, when batteries are used to store power, not only is there additional expense to purchase the batteries and associated equipment, but due to the internal resistance of the batteries there is a small loss of power as the charge is drawn out of the batteries.

2.1.7 PV Systems

Two types of PV systems are grid-connected systems and stand- alone systems. The main difference between these systems is that one is connected to the utility grid and the other is not.

2.1.7.1 Grid-Connected Systems

Grid-connected systems are designed to operate in parallel with, and interconnected with, the national electric utility grid. What is the grid? It is the network of cables through which electricity is transported from power stations to homes, schools, and other places. A grid-connected system is linked to this network of power lines. The primary component of a grid-connected system is the inverter, or power conditioning unit (PCU).

The inverter converts the DC power produced by the PV system into AC power, consistent with the voltage and power quality requirements of the utility grid. This means that it can deliver the electricity it produces into the electricity network and draw it down when needed; therefore, no battery or other storage is needed.

2.1.7.2 Stand-Alone Systems

As its name suggests, this type of PV system is a separate electricity supply system. A stand-alone system is designed to operate independent of the national electric utility grid, and to supply electricity to a single system. Usually a stand-alone system includes one or more batteries to store the electricity. Historically, PV systems were used only as stand–alone systems in remote areas where there was no other electricity supply. Today, stand-alone systems are used for water pumping, highway lighting, weather stations, remote homes, and other uses away from power lines.

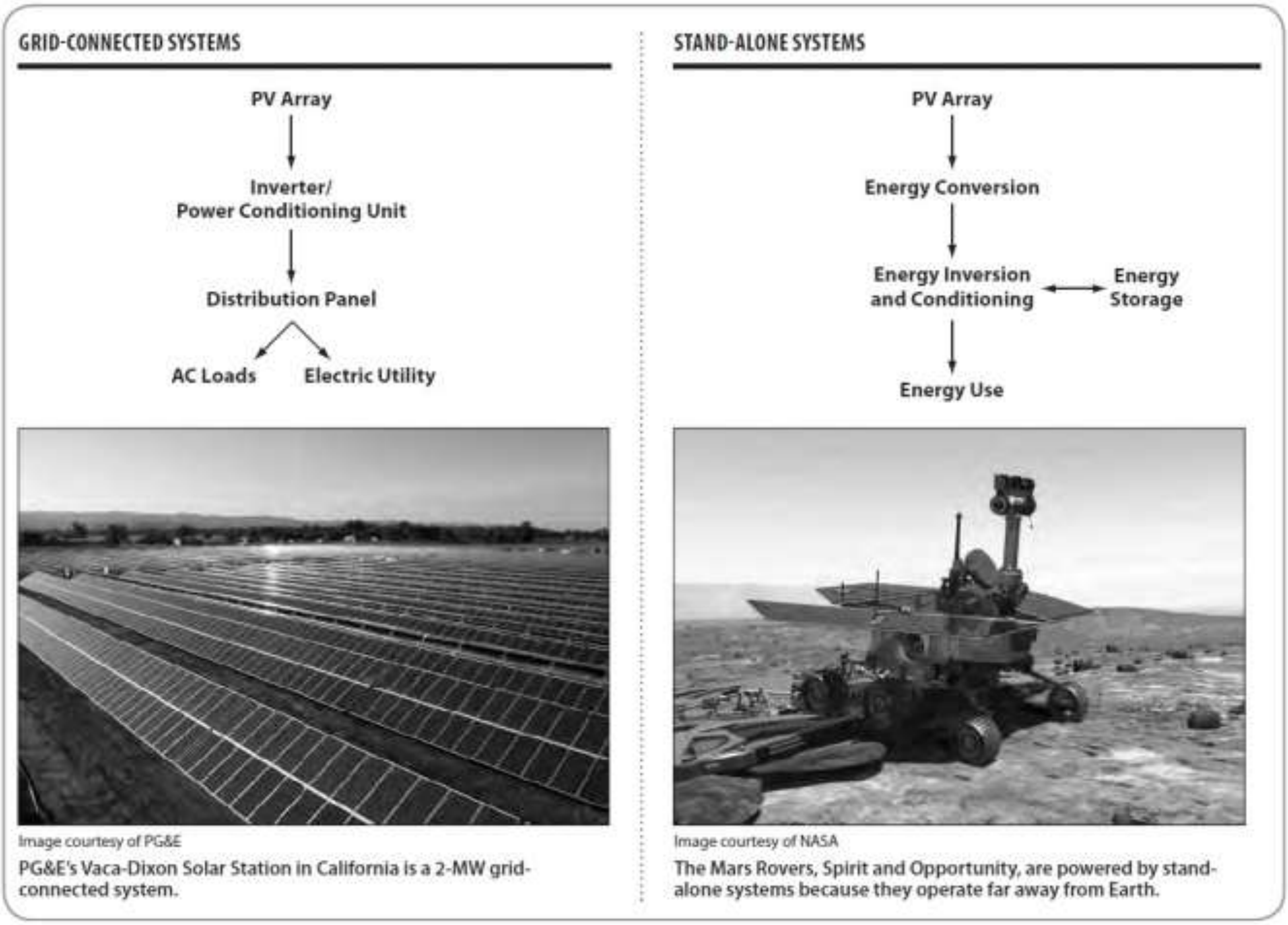

Figure 2.8 PV systems

2.1.8 Scale of PV Systems

There are three general scales at which Photovoltaic systems are generally installed. They are:

2.1.8.1 Residential

A residential system is designed to offset power usage at an individual residence. While usually not able to provide all power used by the homeowners, the system could help to offset the home's electricity usage. This type of system might produce enough electricity to power from one to a fraction of one home's electricity needs.

2.1.8.2 Commercial

A commercial system is designed to offset power usage at a business or industrial site. These systems are much larger than residential systems that can produce more power due to the often expansive roof-top space available for their installation. An example would be a grocery store that contracts with a company to place a solar array on their flat roof while simultaneously contracting to buy power from the installer at a fixed rate for many years. This type of system might produce enough electricity to operate all or part of the business or industrial site.

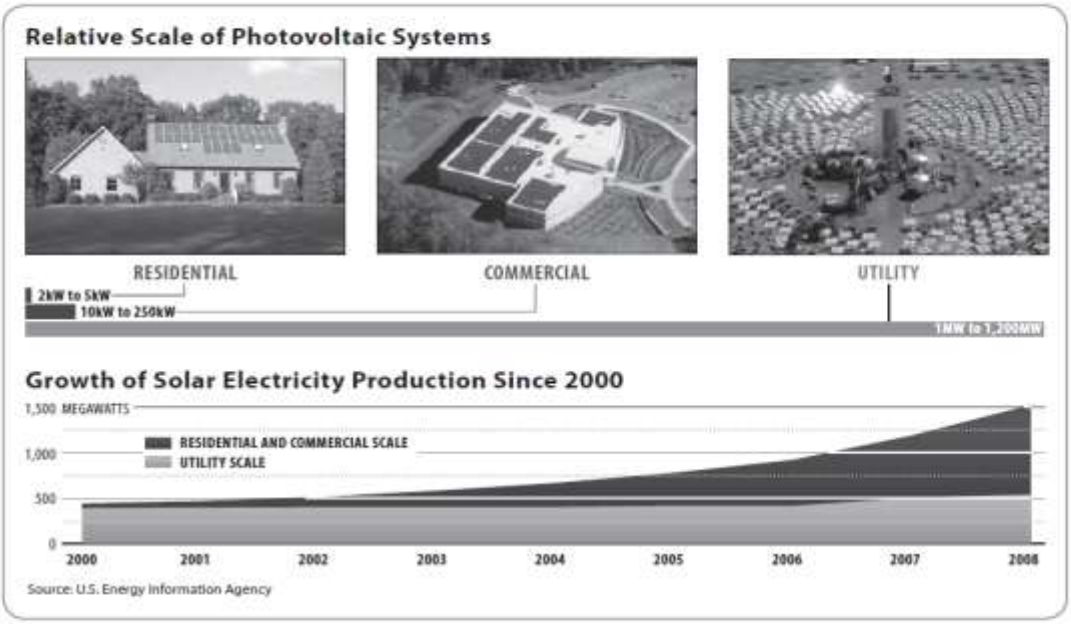

Figure 2.9 Relative Scale Of Photovoltaic Systems

2.1.8.3 Utility

Utility systems are employed by energy companies to produce base-load or peak-load power for sale to consumers. Large areas of land are typically required for their installation. An example would be a large PV array that is employed to produce power at peak usage times in the summer months when air conditioning accounts for a large part of the electrical usage. The array produces the most power when the sun is at its peak and causing consumers to turn down their thermostats—requiring the extra electricity produced by the array. Another example would be a concentrating solar plant that uses parabolic mirrors to focus the sun’s energy on a high efficiency PV array that produces a large amount of electricity to contribute to the grid. Systems at this scale can produce enough electricity to operate hundreds to thousands of homes based on size. The solar insolation values and slope of the site are significant concerns when siting such a plant.

2.1.9 Emerging PV Technologies

Today there are many new PV technologies either on the market, in the pipeline, or in the research phase. These technologies will have a direct effect on how much of our energy we derive from solar power in the future. Look for technologies that will make things less expensive or serve multiple purposes as they are applied to new designs.

2.1.9.1 String / Ribbon Silicon

These use the same materials as typical crystalline silicon. It is drawn out of molten silicon rather than being sawed from an ingot, thereby making it less expensive to produce. In some cases, this manufacturing method can produce PV cells that have higher conversion efficiency than that of cast silicon.

2.1.9.2 Amorphous Silicon / Thin-Film Technologies

This new class of materials allows the production on PV cells that are smaller and more flexible than the delicate silicon wafer technology that has dominated PV cell production in the past. These materials are not crystalline in structure. This type of PV cell can actually be applied to a

variety of materials to make any number of materials that you might use for another purpose—such as glazing for a window, or shingles for a roof. Imagine windows that produce electricity! Materials used for dual purposes (building material and PV cell) are called **Building Integrated Photovoltaics** (BIPV).

2.1.9.3 GaAs: Gallium Arsenide

Used in high-efficiency applications—space craft and concentrating solar power—very expensive

2.1.9.4 CdTe: Cadmium Telluride

This thin-film technology has a great deal of potential; however, there are concerns about the chemicals necessary for its production.

2.1.9.5 CIS: Copper Indium Diselenide

Provides efficiencies up to 17 percent but manufacturing processes are material specific.

2.1.9.6 CIGS: Copper Indium Gallium Diselenide

These materials are generally applied to PV cells to increase the energy absorption of the cells. Thin-film materials are much cheaper to produce. They are very versatile in how they can be applied to many structural materials. They are also less efficient than current silicon crystal PV cells. However, what they lack in efficiency may be overcome by their flexibility of application and low cost.

2.1.9.7 Multi-junction Technologies

This category actually combines multiple layers of materials that are designed to absorb different wavelengths of solar energy— improving the efficiency of the cell by combining the output of the various layers. These devices are currently in the research phase, but the concept has been proved.

2.1.10 Benefits and Limitations:

2.1.10.1 Benefits

Solar electric systems offer many advantages such as:

• They are safe, clean, and quiet to operate.

• They are highly reliable.

• They require virtually no maintenance.

• They are cost-effective in remote areas and for some residential and commercial applications.

• They are flexible and can be expanded to meet increasing electrical needs.

• They can provide independence from the grid or backup during outages; and

• The fuel is renewable and free.

2.1.10.2 Limitations

There are also several practical limitations to PV systems:

• PV systems are not well suited for energy-intensive uses such as heating;

• Grid-connected systems are rarely economical, primarily because the current cost of the PV technology is much higher than the cost of conventional electricity in the United States.

Photovoltaic/Thermal Systems

2.2 Introduction

PV/T is defined as a device using PV as a thermal absorber. By using the heat generated in the PV, a PV/T device generates not only electrical, but also thermal energy. Because of this scope, no attention will be paid to side-by-side systems, in which PV is installed next to solar thermal in the same frame.

2.2.1 Definition of PV/T Collector

A photovoltaic/thermal hybrid solar collector is a combination of photovoltaic (PV) and solar thermal (T) components/systems which produce both electricity and heat from one integrated component.

PV systems turn on average less than 20% of the sunlight into electricity. The remainder is turned into heat. Utilizing this untapped energy is the general concept for hybrid systems. Through the application of systems that can provide both (thermal and electrical), the energy yield per area unit of roof or facade can be substantially increased. Further advantages are using heat transfer from PV-module, improvement of conversion efficiency of solar cells, increase of electric output and an aesthetically appealing more uniform look.

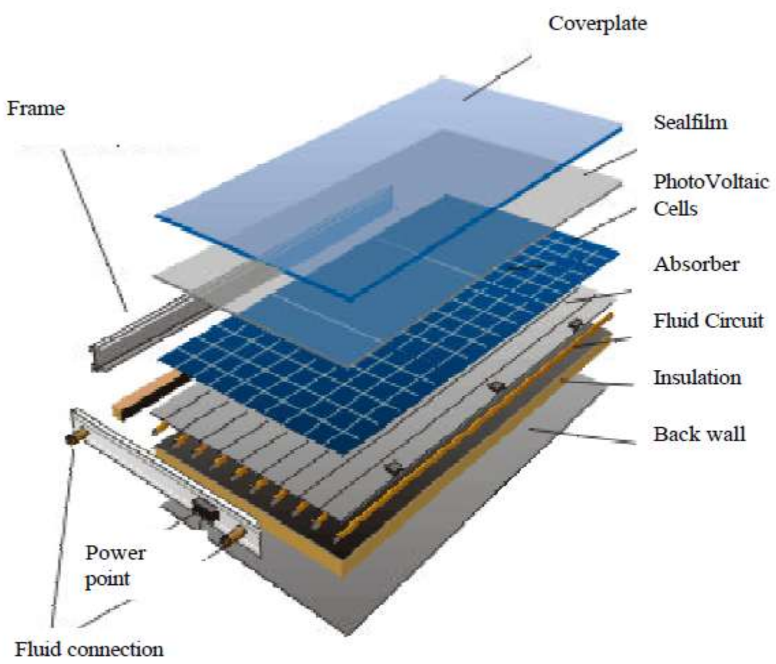

Figure 2.10 Construction of a PV/T Collector

2.2.2 Module overview

PV/T modules can be characterized along several dimensions, such as the type of PV used, whether the collector is glazed or unglazed, what collector fluid is used (water/glycol or air), whether concentration is used and what type of module design was used.

2.2.2.1 Points of Attention

The effect of PV type and glazing are indicated:

Glazing

PV/T collectors may have a glass cover over the absorber to reduce the thermal losses. If such a cover is present, the collector is referred to as "glazed", otherwise as "unglazed". The terms "glazed" or "unglazed" therefore do not refer to the glass substrate that may be part of the PV/T absorber!

- Glazed collectors have smaller thermal losses, especially at higher collector fluid temperatures. For medium to high temperature applications, this results in a much higher annual thermal yield.
- Glazed collectors result in high stagnation temperatures that may be critical for certain types of PV encapsulant (risk of yellowing and delamination). The glazing makes the module more sensitive to hot spots. Bypass diodes may get overheated due to the additional insulation. Reflection losses at the glazing reduce electrical performance. Increased temperature levels lower the electrical yield.

In the discussion whether the collector should be glazed or not, it is important to find a good balance between the increased thermal yield on one hand, and the reduction in electrical yield and the issues related to possible degradation on the other hand.

Types of PV

Several commercial PV technologies exists such as:

- Crystalline silicon (c-Si) which divided into two types:
  1) polycrystalline Si (multi Crystal silicon)
  2) monocrystalline Si (single Crystal silicon)

- Amorphous silicon (a-Si) which divided into two types:
  1) amorphous -Si (single junction)
  2) amorphous -Si (triple junction)
- HIT cells
- Ribbon & EFG cells
- CIS
- CdTe.

Crystalline silicon has by far the largest market share of all PV technologies, as shown in Figure 2.11. Commercial modules have a good electrical efficiency of 10-17% for mono crystalline silicon modules and 11-15% for polycrystalline silicon modules. A good electrical efficiency is important, since for many applications, PV/T produces too much heat relative to electrical energy.

Amorphous silicon has a significant market share, but much smaller than c-Si. It has a relatively low electrical efficiency of 4-6% for single junction and 5-7% for triple junction material. It can be obtained in flexible laminates, increasing the design options. The price per square meter for a-Si is lower than for c-Si. However, this is compensated for by the lower efficiency of a-Si; the price per W_P for a-Si is similar to the price for c-Si.

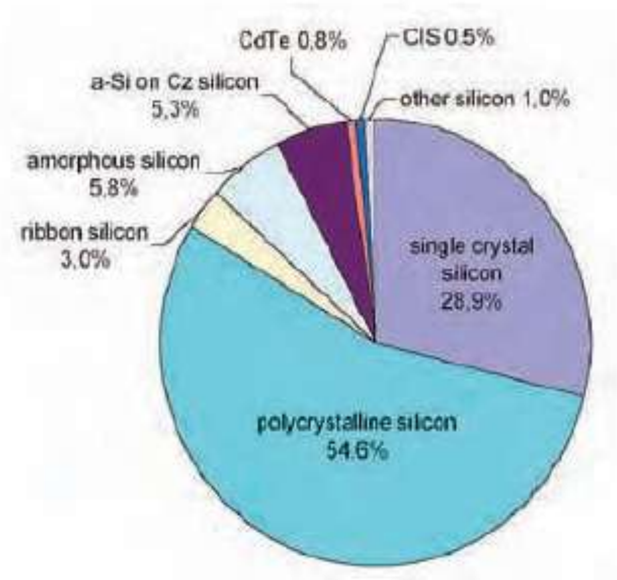

Figure 2.11 Market share of PV technologies 2002 (figure from PV-NET roadmap, data from P.D. Maycock)

Other PV techniques such as CIS and CdTe are upcoming but have presently a very small market share and have therefore not yet been used in PV/T.

On the system level, only the effects of climate, orientation and temperature affect the electrical performance of a given PV/T system. The most important effects are those of total annual irradiation and the effect of orientation, which is a function of latitude. This leads e.g. to the observation that, from an efficiency point of view, facade integration is more appropriate for Northern countries.

Of secondary importance is the effect of temperature. It is different for different types of PV. For most thin film cells the temperature coefficients -The temperature coefficient is efficiency reduction at every ^{o}C temperature increase - is smaller than for crystalline silicon cells, so the losses may be only about half the losses compared to crystalline silicon cells. However, all cells have negative temperature coefficients which mean that the situation is in principle still the same (less energy produced at higher temperatures).

However, the effect of the power dependence on the temperature should not be overestimated. During operation (enough daylight) a c-Si PV module has an average temperature over the year of about 30-40 ^{o}C (depending on the amount of ventilation of the module), whereas a glazed PV/T collector may have an average temperature between 30 ^{o}C and 50 ^{o}C (depending on the solar fraction). So we can estimate that the electrical power loss will generally be less than about 10% of the total electrical yield.

2.2.2.2 Classification of PV/T Collectors

There are various types of PV/T collectors according to fluid which transfer heat, using of thermal energy, reducing thermal losses and shape of collector as following:

A. PV/T liquid Collectors

The liquid PV/T collectors are similar to conventional flat plate liquid collectors; an absorber with a serpentine tube or a series of parallel risers is applied, onto which PV has been laminated or glued.

For these systems, water is used as heat transfer fluid. The PV cells are pasted either directly on the absorber or interior on a cover plate with a dielectric material. This means that the only contact between the PV cells and the absorber or the cover plate is a high thermal contact. The heat

transfer fluid runs inside the ducts or pipes on the absorber and collects heat from the absorber. If the PV cells are pasted to the absorber, heat is also extracted from the PV cells resulting in a higher electrical efficiency of the PV cells.
Useful thermal energy is extracted to one end of the ducts where it can be utilized. The ducts can be coupled either in series or in parallel, which affects the efficiency of the system. The heat transfer fluid can be circulated by either a pump (a pumped system) or by the difference in specific gravity of the heat transfer fluid (a gravity system).
Special integrated PV/T absorbers are required, for which the thermal resistance between PV and collector fluid should be sufficiently small (especially for unglazed PV/T). Leakage or freezing may occur in case of faulty design.

Figure 2.12 PVT liquid collector

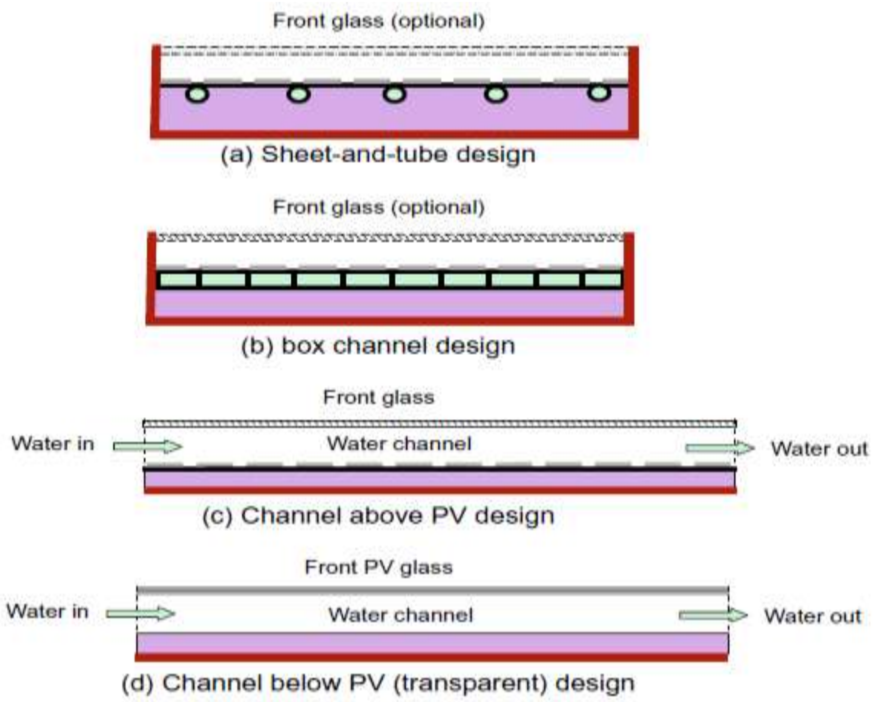

Figure 2.13 Cross-sections of some common PVT/w collector designs

B. PV/T air collector

The PV/T air collectors are similar to a conventional underflow air collector with a PV laminate functioning as the top cover of the air channel. PV/T air collectors have the important advantage over PV/T liquid collectors that conventional PV modules can be used, which reduces the module costs relative to PV/T liquid modules. However, this benefit on module level may be compensated by increased costs and lower annual yields on systems level. PV/T air collectors can either be glazed or unglazed. The air can be circulated by either natural ventilation or forced ventilation.

Figure 2.14 PVT air collector

The application of air as a heat transport medium has some advantages but also some big disadvantages in comparison with water.

To start with the advantages:

- No freezing and no boiling of the collector fluid.
- No damage if leakages occur.

The disadvantages are however rather severe:

- Low heat capacity and low heat conductivity, which result in a low heat transfer.
- Low density, which results in a high volume transfer.
- High heat losses through air leakage

For direct heating of living rooms, heating air to more than 60°C is not recommended. Air with a temperature of more than 60°C is starting to burn dust particles, which can lead to health problems in open systems. Also particles of the materials in the PV/T collector may be gassing out at high temperatures.

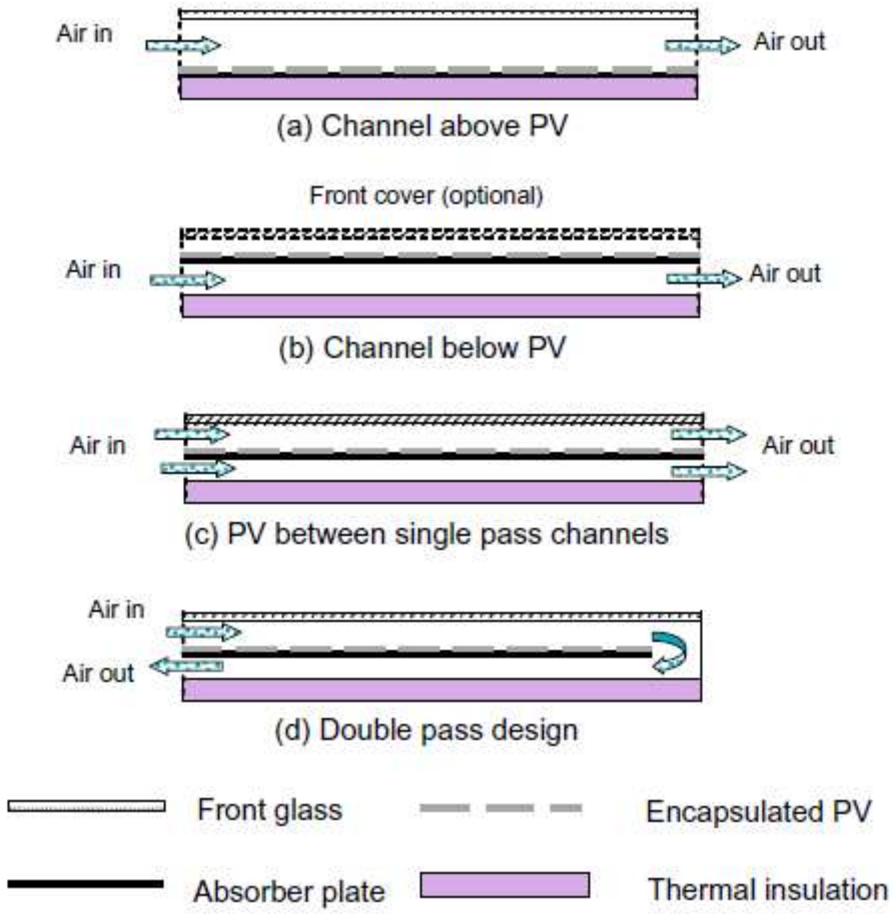

Figure 2.15 Longitudinal cross-sections of some common PVT/a collector designs

C. Ventilated PV with Heat Recovery

In conventional PV facades or PV roofs, an air gap is often present at the rear in order to allow the air to cool the PV by means of natural convection (ventilated PV). If this heat can be recovered from the PV and be used in the building, the PV functions as a PV/T collector.
Basically, the entire PV/T-module infrastructure is already available in normal building integrated PV. Such PV facades, apart from providing electricity and heat, have additional benefits as well:

- A PV-facade may limit the thermal losses from the building to the ambient (especially those related to infiltration). In addition, the PV facade shields the building from the solar irradiance, thereby reducing the cooling load. This makes such facades especially useful for retrofitting badly insulated existing offices.
- Air collectors and PV-facades can use their buoyancy induced pressure difference to assist the ventilation, if there is no demand for

the generated heat.

- Facade integration of PV has the cost incentive of substituting expensive facade cladding materials.

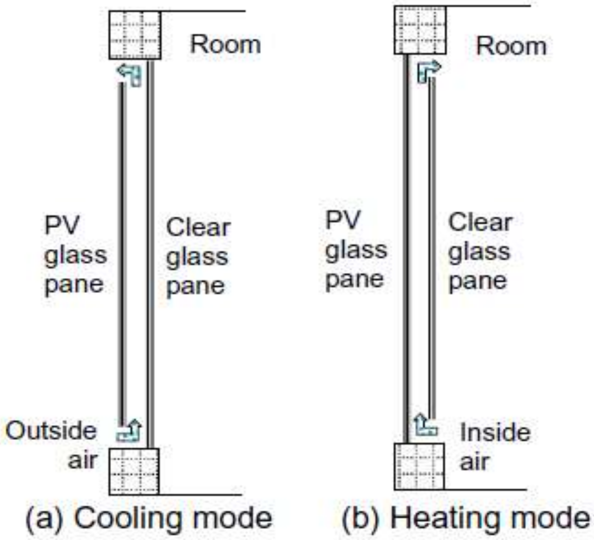

Figure 2.16 Different modes of ventilated PV glazing operation

Similar to PV/T air collectors, a problem for ventilated PV is the limited application for hot air during the summer, when most heat is available. An interesting option is the application of the heat for solar cooling. However, the temperature level that can be reached by the ventilated PV is not sufficient for direct use in such systems, due to the large heat losses and the facade orientation. Therefore, ventilated PV/T facades are combined with roof or facade integrated conventional collectors to boost the temperature to the required level for this application.

Figure 2.17 Ventilated PV with heat recovery

Since the heat transfer from the PV to the airflow is generally not very good, the losses to the ambient are large and thermal efficiencies are generally in the range of 10% to 20% for a well-designed system.

Because of health reasons, direct introduction of the heated air into living rooms is not recommended. Fungi and bacteria in the duct systems cannot be avoided, as well as dust that will be blown into the living rooms. Although filters could clean the air, maintenance is difficult and the pressure drop and therefore the electrical power for ventilation will increase significantly. This is why indirect systems (hypocausts, double wall systems...) are used for air heating systems in living rooms. However these systems are much more expensive.

D. PV/T Concentrators

By concentrating, a (large) part of the expensive PV area is replaced by cheap mirror area, which is a way to reduce the payback time. This argument is the driving force behind PV-concentrators. However, this leads to a substantial thermal energy generation in the solar cells, and if not removed, a very high operating temperature of the solar cells will be the consequence and the efficiency for solar cells will decrease substantially. Therefore, the PV needs to be cooled. If this is done by active means, a PV/T concentrator results. Different types of concentrators exist, ranging from flat plate concepts with added reflectors to highly concentrating designs that strongly deviate from the flat-plate concept.

Figure 2.18 PVT concentrator

The small cell area allows the use of more efficient and expensive PV material, such as cells specially designed for PV/T performance. The combination of glazing and reflectors increases the stagnation temperature, which may lead to degradation of materials. For electrical performance, the uniformity of the irradiance may be compromised, increasing mismatch losses. However, this drawback might be overcome by using diffuse reflectors.

2.2.3 Relation between type of collector and type of demand

A relation exists between the type of module required and the types of demand. An overview is presented in Table 1 below.

Table 2.1 Relation between type of collector and type of demand

Type of demand	Recommended type of PV/T collector
high temperature water	Use glazed liquid collector, glazed air collector with heat exchanger or concentrator. Also an unglazed collector is possible as source for a heat pump.
high temperature air	Use glazed air collector or unglazed collector/ventilated PV as source for a heat pump.
low temperature water	If only summer demand use unglazed liquid collector, if also winter demand use glazed liquid collector or unglazed collector as source for a heat pump.
low temperature air	If only summer demand or high irradiation in winter use unglazed air collector or ventilated PV. If also winter demand and low irradiation in winter, use glazed air collector or unglazed collector as source for a heat pump.